Rover Autonomy Architecture Automated Reasoning (CLARAty)

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CLARAty Team:

JPL Robotics, JPL AI

Ames Research Center

Carnegie Mellon University

Rover Autonomy Architecture (CLARAty)

PI: Issa Nesnas (JPL), Co-I: ARC, CMU

Goal: Develop a unified and reusable framework for robot control and autonomy that facilitates the integration of new technologies on various robotic and rovers platforms

Objectives:

- Develop robotic infrastructure (or *Functional Layer*) that provides capabilities for exercising high-level autonomy algorithms. Such capabilities include motion control, locomotion, manipulation, position estimation, path planning, navigation, manipulation, resource estimation, and communication with other systems
- Integrate with high-level autonomy algorithms such as planning and execution (or *Decision Layer*).
- Share the same rover models between both layers and query for resources and state updates

Accomplishments to date:

- Demonstrated Decision/Functional Layer interaction on two rovers, Rocky 8 and Rocky 7
- Developed communication infrastructure and mechanisms for sharing large data set representations between the Functional Layer and the Decision Layer. Such sets include real terrain maps and stereo image pairs
- Design infrastructure to interact with ROAMS and other rover simulations

Schedule

- FY01: Integration of high-level autonomy (DL) with mid-level rover autonomy (FL) for real and simulated rovers
- FY02: Demonstrated above on real rovers (resource queries, power/memory models, state updates, dynamic replanning).
- FY03: Generalize infrastructure to support other DLs and provide tighter integration with Functional Layer

DYNAMIC REPLANNING
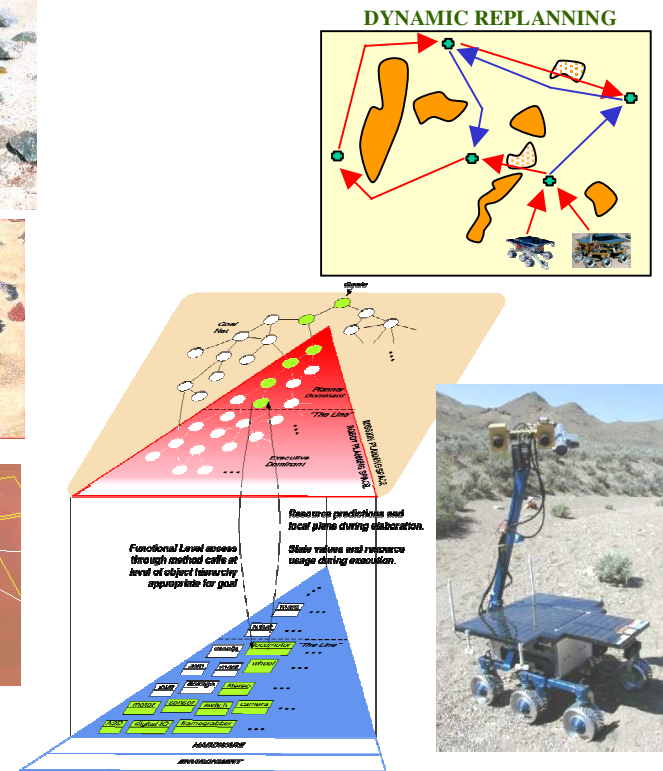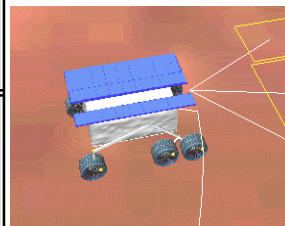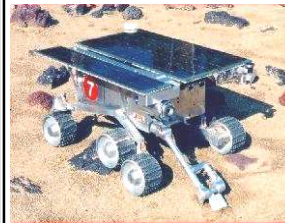
NASA Relevance & Benefits:

- Provides generic robotic infrastructure for integrating various robotic and autonomy technologies
- Can be adapted to various research and flight rovers in relatively short period of time
- Provides a robust multi-platform infra-structure for testing autonomy software (e.g. planning and execution)
- Enables testing certain flight software (e.g. navigation) on various research prototype rovers.

Task Overview

General

- Make all rover prototypes viable for testing decision layer capabilities

Specific

- Design and build infrastructure to allow Decision Layer and Functional Layer to share large data sets such as terrain maps acquired from panoramic imagery

- Unify models and provide access to Decision Layer for information and algorithms that are used to control the rover

- Design and build a generic infrastructure to support various path planners needed by Decision Layer

- Design and build generic infrastructure to support various types of navigation algorithms to support Decision Layer activities such as "goto location"

A Two-Layered Architecture

CLARAty = Coupled Layer Architecture for Robotic Autonomy
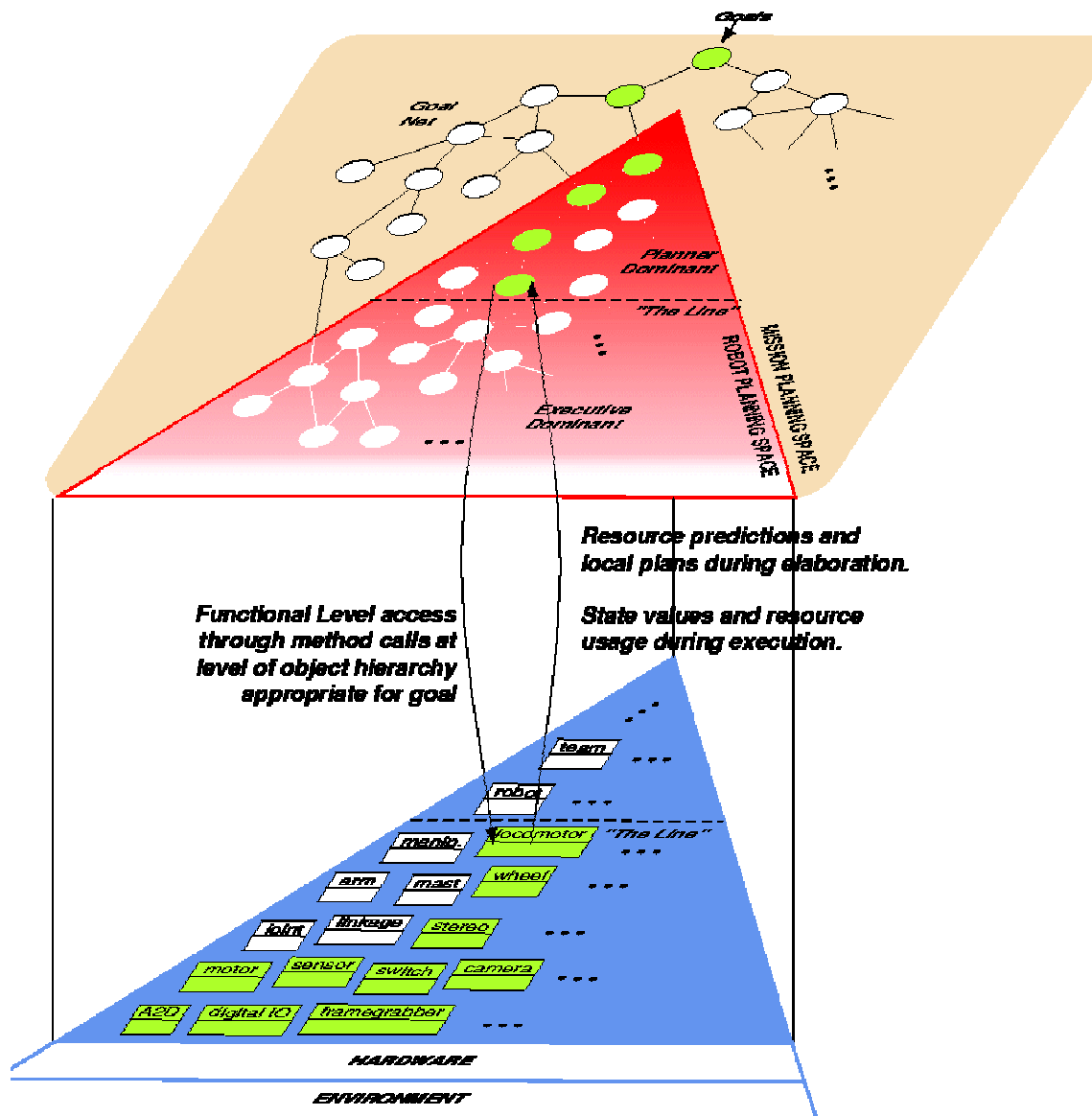
THE DECISION LAYER:
Declarative model-based
Mission and system constraints
Global planning

INTERFACE:
Access to various levels
Commanding and updates

THE FUNCTIONAL LAYER:
Object-oriented abstractions
Autonomous behavior
System functionality/Low-mid level
autonomy

Adaptation to a system

Currently Supported Platforms

Rocky 8

VxWorks

Intel x86

JPL

Intel x86

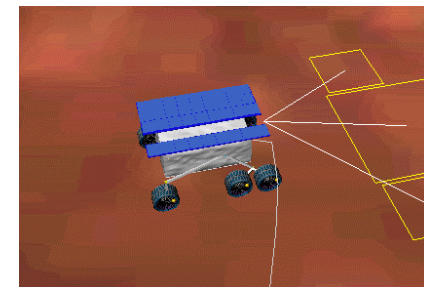Linux

CMU

Solaris CC

JPL AI

K9

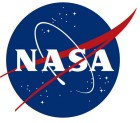Linux

Intel x86

Ames

Rocky 7

VxWorks | Motorola 68K

JPL

ROAMS

Solaris

JPL

Adapting to a Rover

The Decision Layer

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The Functional Layer

Rover

Navigation

Path Planning

Estimation

Transforms

Motion Control

Input/Output

Behaviors

Manipulation

Vision

Math

Communication

Hardware Drivers

Simulation

Locomotion

Science

Sensor

Adaptations

Rocky 8

FIDO

K9

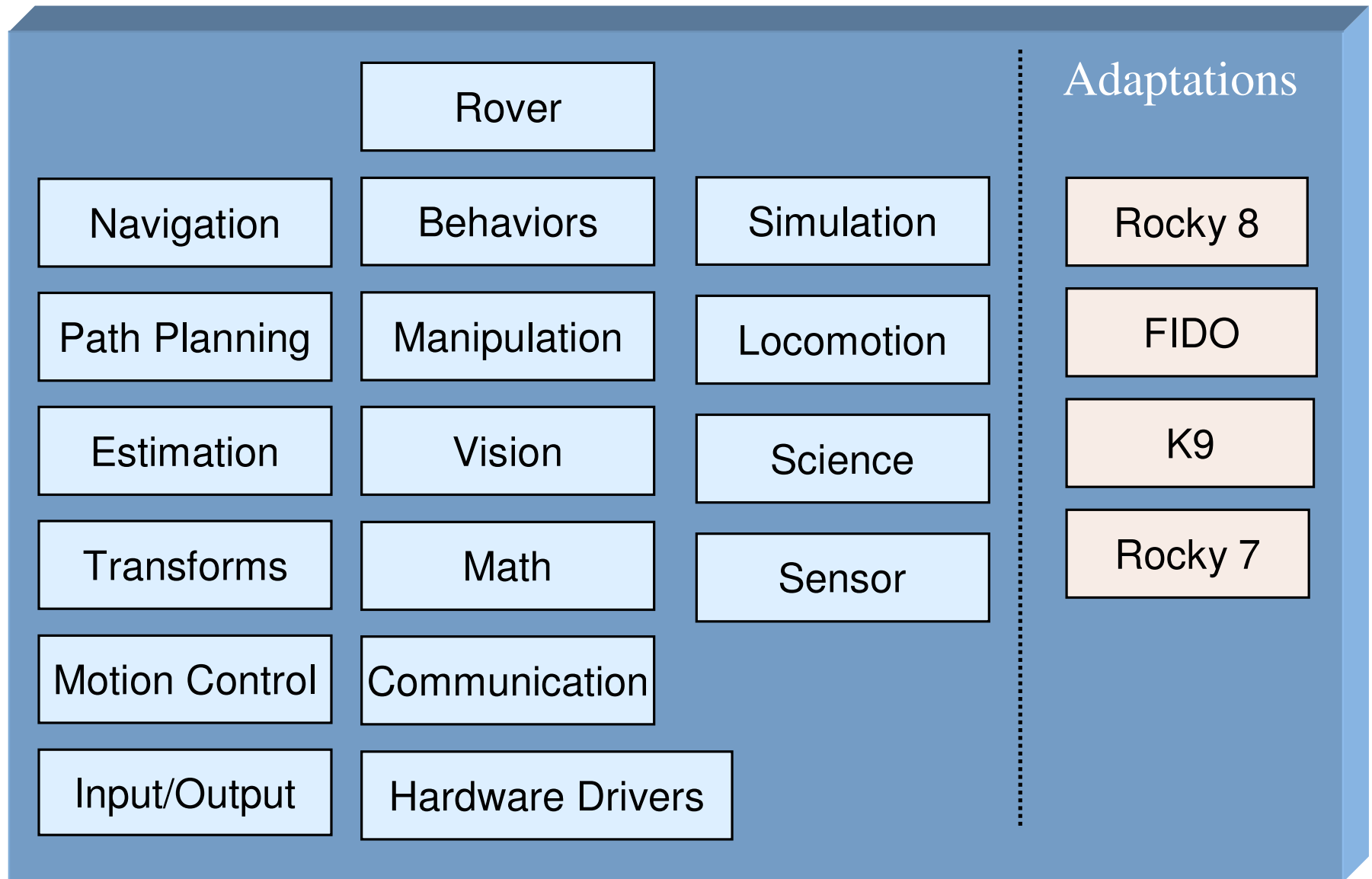Rocky 7
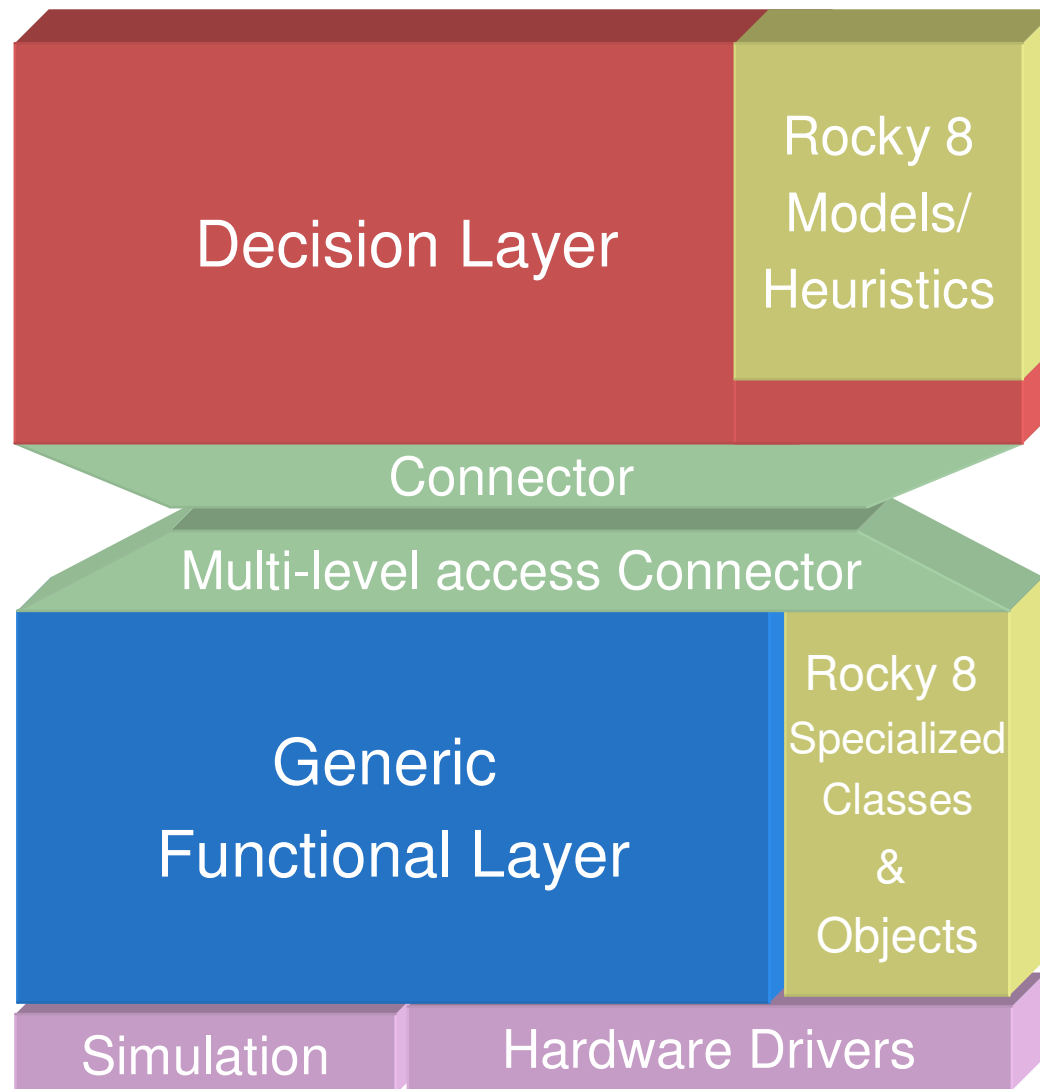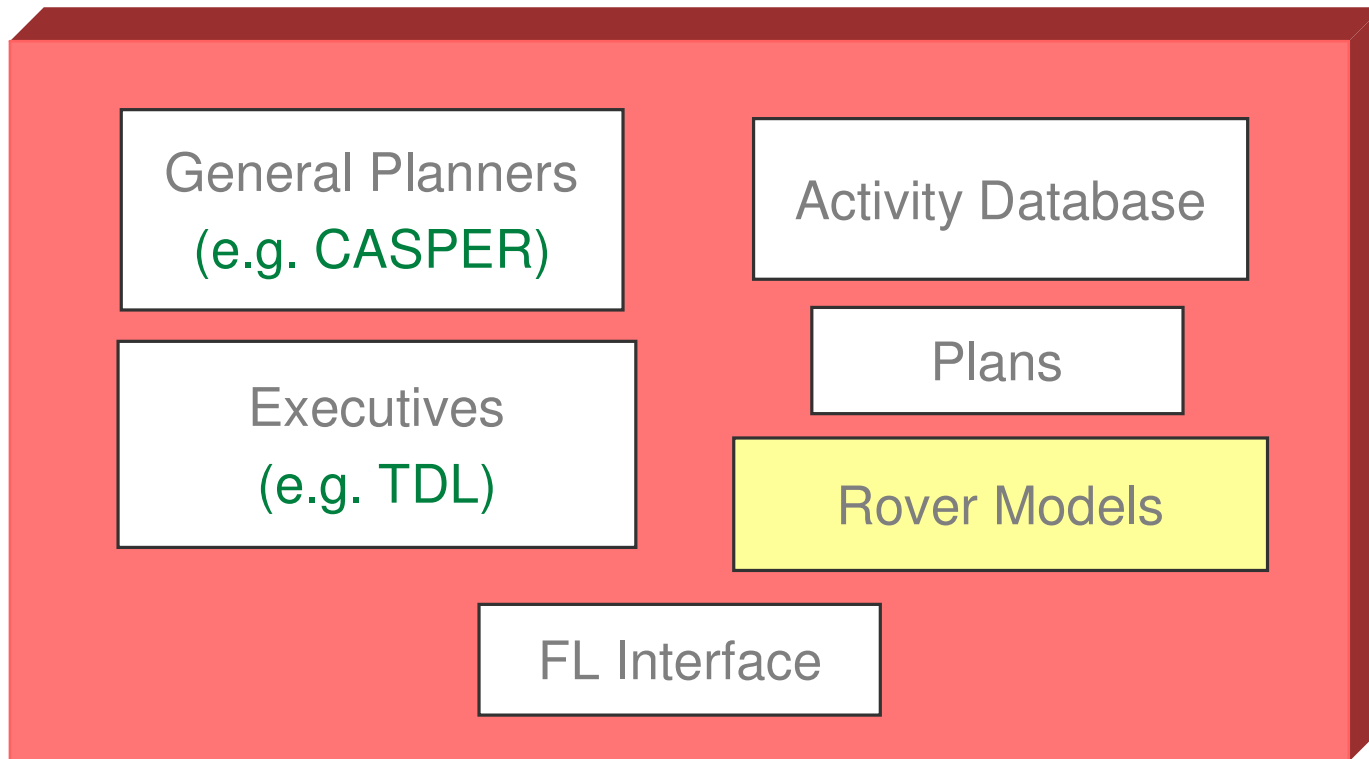
Key Research Objectives

- Unifying the rover models and algorithms used by the Decision Layer and the Functional Layer

- Using a client-server model where the Decision Layer commands and queries the Functional Layer for resource estimates and receive requested periodic updates of various rover states

- Intentional overlap in functionality to allow exploration of various levels of interactions between the Decision Layer and the Functional Layer

- Provide an infrastructure that allows overall DL/FL systems to deal with interchangeable modules such as different navigators, locomotors, path planners, executives and general planners

- Factor out general behaviors that are applicable to a particular domain (e.g. rovers)
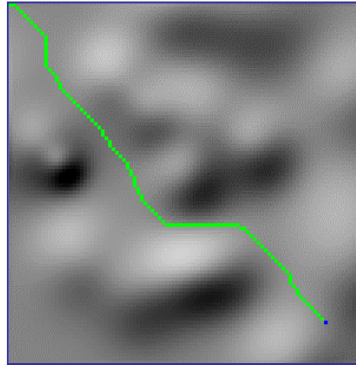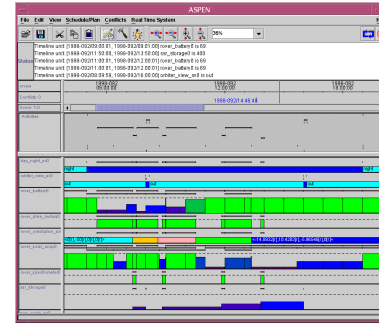
Recent Accomplishments

- Demonstrated on Rocky 8 a multiple-goal scenario where rover sequence must be modified dynamically to accommodate unexpected situations
  - Used new pose estimation capability that provides more accurate heading estimation
  - Collaboration with CLEaR and Integrating Planning tasks

- Created a goodness map from single- and multi-tier Rocky 7 panorama
  - Enables information on panoramic elevation maps to be shared between Functional Layer and Decision Layer
  - Goodness map is used to provide path-planning information to Decision Layer

- Developed a Power System module that supports power management of various entities, solar panels, batteries, chargers

- Developed a Device and Telemetry module that provides a flexible and extendible generic mechanism for reading telemetry from all system devices and querying system devices, and provides consistent support for command registration and query.
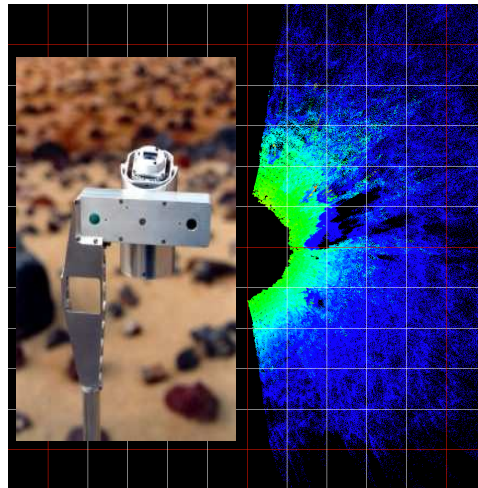
Sharing of Terrain Information
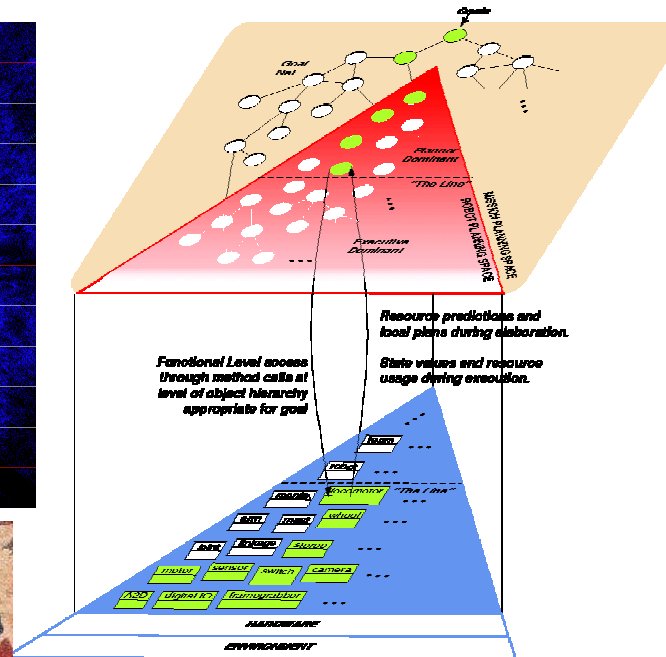
Selected Path

D* Global Cost Function

Goodness Map

Panorama Seaming

Panorama Acquisition
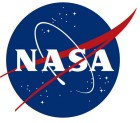
DECISION LAYER

FUNCTIONAL LAYER

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Recent Accomplishments, cont.

- Integrated and demonstrated Decision and Functional Layer CLARAty system on a ROAMS rover simulation
  - Rover level interface with power, resource, and memory updates
  - Lower level interface with simulation to be completed by Oct 1, 2002.
  - Tested Decision Layer with integration path planner using ROAMS rover simulation
- Interactions with MSF team and science autonomy team at ARC
- Unifying models and algorithms such as path planner (e.g. D*, Tangent Graph) to be specialized version of generic path planners used by both layers
- Started discussion with Ames and CMU to extend FL/DL interface to support various types of Decision Layers
- Submitted documentation for ITAR evaluation of CLARAty (FL/DL)
- CLARAty rover software repository accessible for multiple institutions (currently open to team members)
  - Integrating CLARAty DL (CASPER/TDL/CLEaR) into repository

Current and Future Directions

- ## Current Work:
  - Streamline the process of commanding, acquiring and sharing of terrain data between two layer. Currently, the process is semi autonomous.
  - Test the integration of D* with the CASPER planner on a real rover using updated position estimation, navigator and locomotion
  - Provide higher fidelity interface for rover simulations

- ## Future Work:
  - Generalize interface between Decision Layer and Functional Layer to support other types of Decision Layer
  - Continue to unify models and algorithms shared between the two layers
  - Continue interactions with K9 (Bualat), visual servoing (Bandari), Instrument Placement (Pedersen), MSF team (Pisanich), science autonomy (Roush), executive (Washington, Bresina), and fault detection (Deardren) teams
  - Provide solid user level documentation for CLARAty
  - Improve robustness and ease of use of various modules
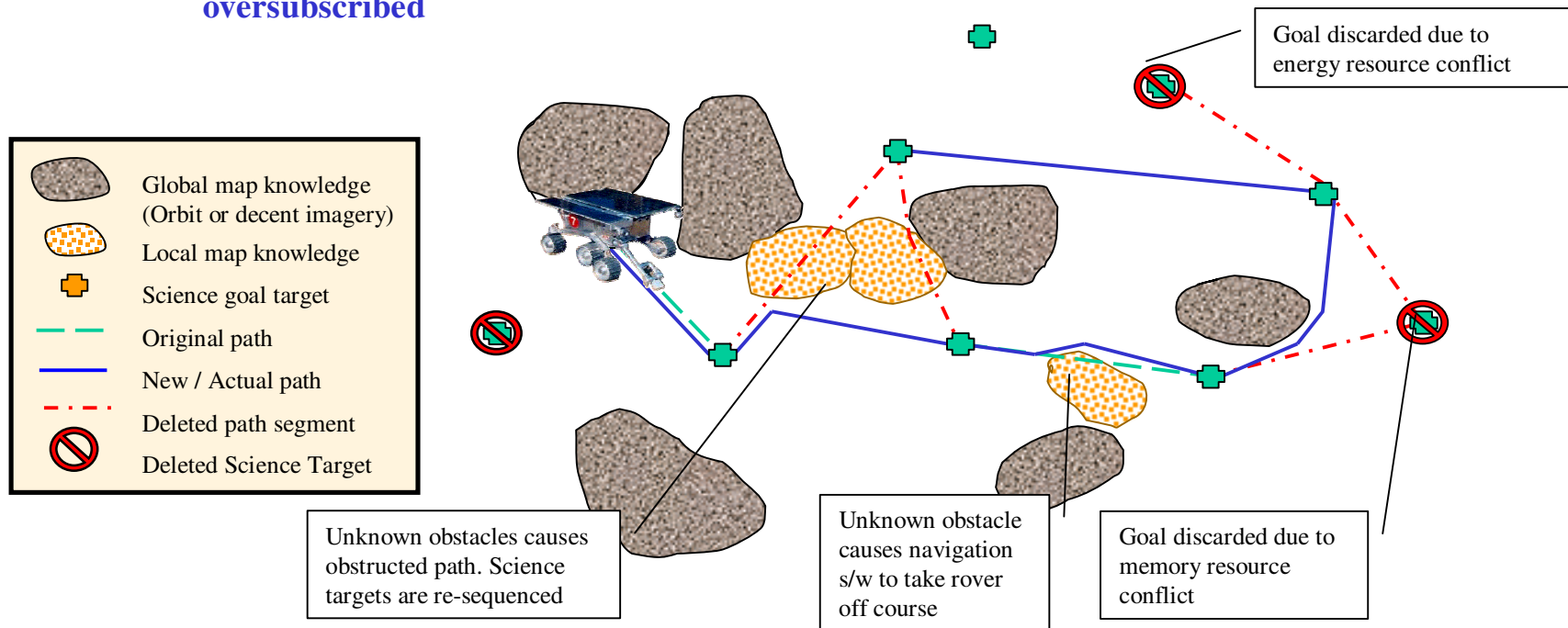 - Integrate various technologies into CLARAty framework

Backup Slides

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CLARAty Decision Layer Running Real Rovers

- Demonstrated a multi-target science scenario using CLARAty Decision Layer (CASPER/TDL) interacting with the Functional Layer
  - **Ran Rocky 8 rover through a science scenario demonstrating replanning capabilities of the Decision Layer**
  - **Ran Decision Layer on both Rocky 8 and Rocky 7 rovers (even simultaneously)**
  - **Demonstrated autonomous planning and re-planning capabilities for rover surface exploration. Will handle situations where power, time, or memory constraints get oversubscribed**

Goal discarded due to energy resource conflict

Global map knowledge (Orbit or decent imagery)

Local map knowledge

Science goal target

Original path

New / Actual path

Deleted path segment

Deleted Science Target

Unknown obstacles causes obstructed path. Science targets are re-sequenced

Unknown obstacle causes navigation s/w to take rover off course

Goal discarded due to memory resource conflict

Planned Accomplishments for Next Quarter

- Accomplishments
  - Develop necessary infrastructure for commanding from the Decision Layer a panorama of a rover platform using mast imagery
  - Start testing this capability on a rover platform
  - Why is it significant to the customer / NASA?
    - It will provide the necessary infrastructure to test planning and execution technologies using realistic terrain data as opposed to relying on apriori hand-crafted maps
    - This will allow a closer integration and sharing of information between the Decision Layer and Functional Layer of the CLARAty architecture.
  - What is the technical significance?
    - Instead of relying on a static map of the site apriori, the Decision Layer will be using a freshly acquired panaroma generated from the stereo imagery of the rover's mast
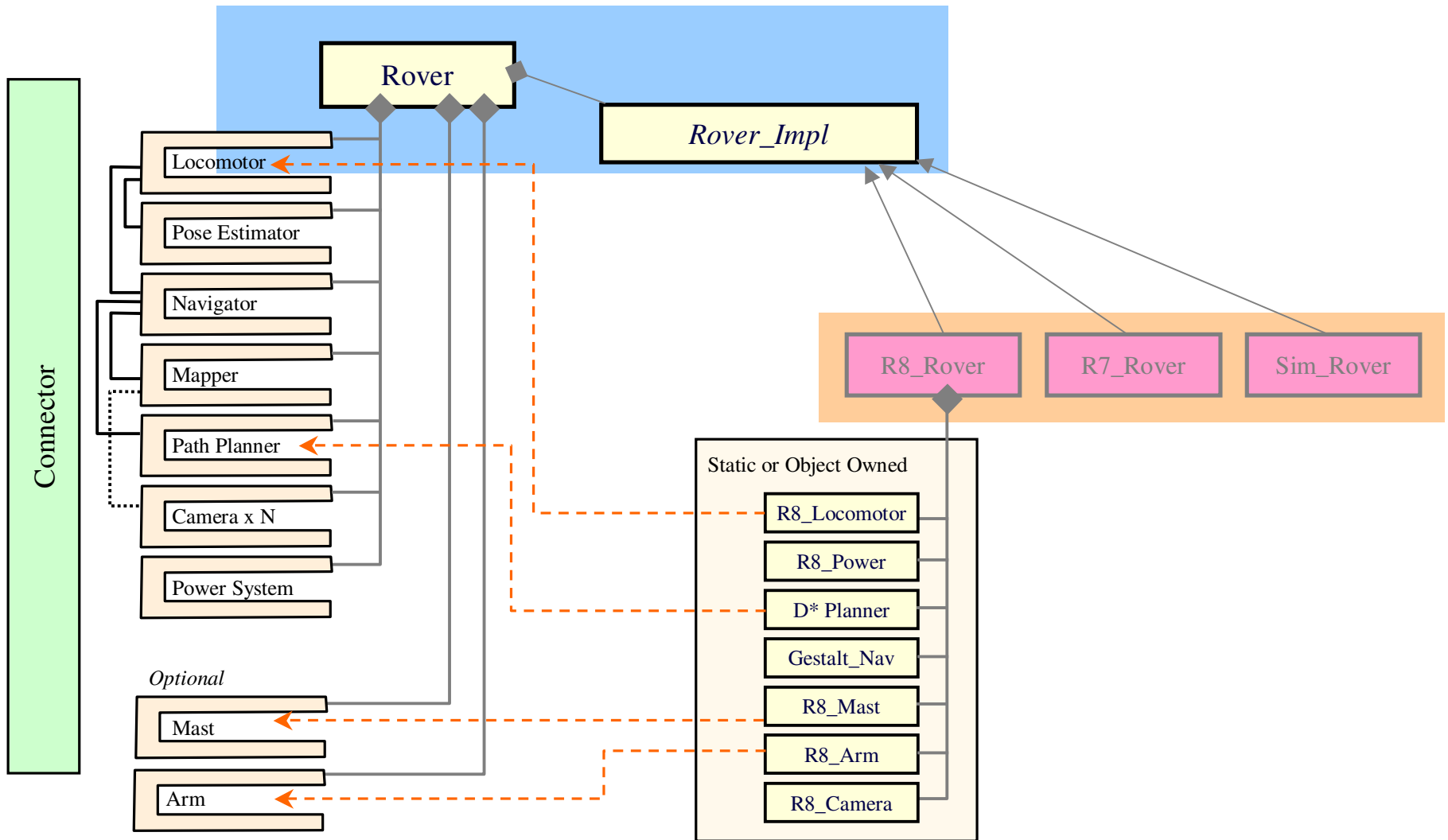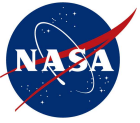
Mission Relevance

Why is CLARAty Architecture work relevant to the missions?

- Provides a *common environment* for development, test, and comparison of advanced robotic technologies
- Provides a robust multi-platform infra-structure for testing autonomy software (e.g. ASPEN/CASPER)
- Provides an infusion path for robotics technologies into flight missions
- Demonstrates technologies on relevant robotic systems
- Makes research rovers viable test platforms for flight algorithms
- Is robust to changes in rover hardware designs
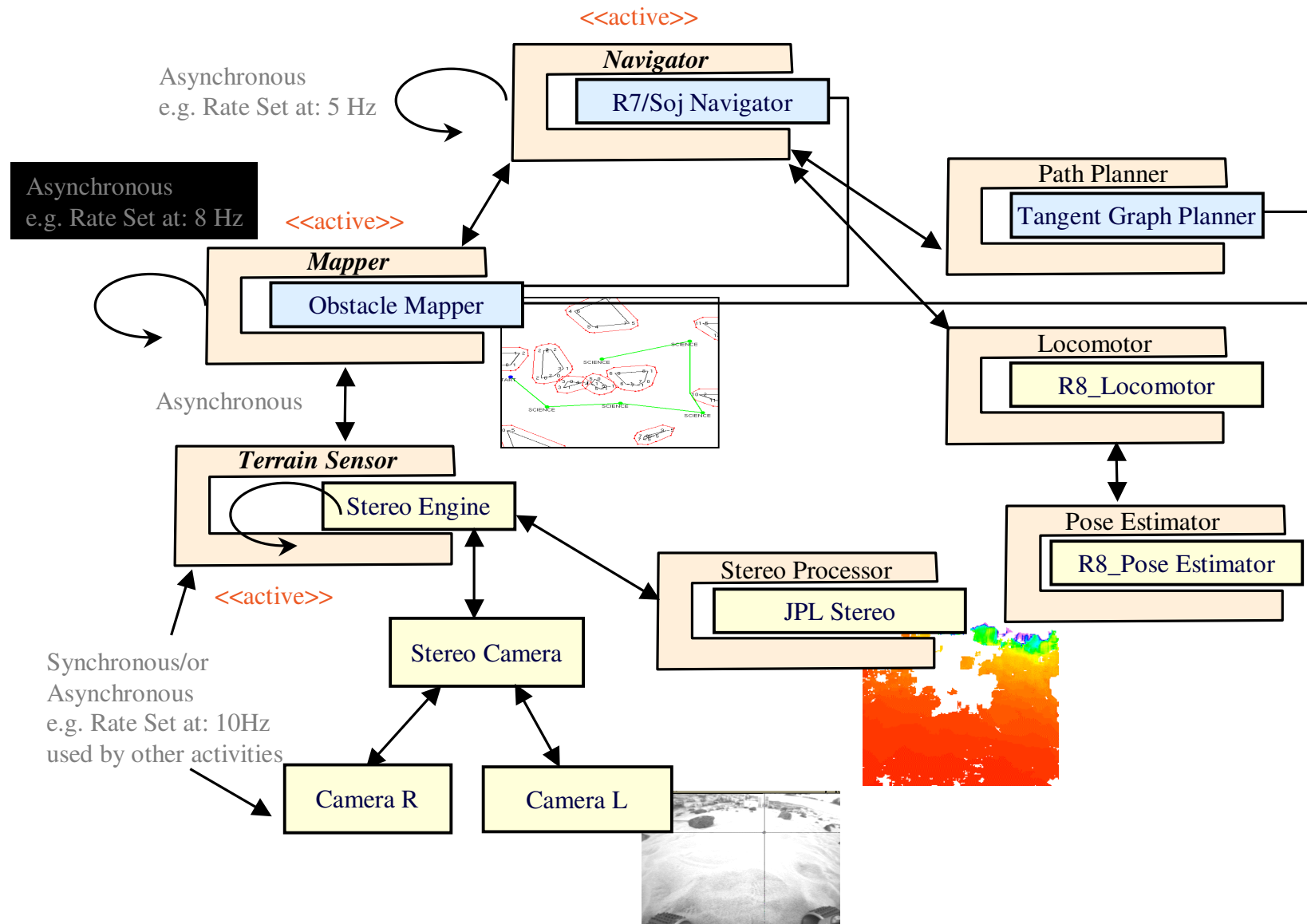- Can be easily adapted to flight and new research rovers

Top Level - Rover Abstraction in FL

Example of Navigation Architecture

Asynchronous
e.g. Rate Set at: 5 Hz

Asynchronous
e.g. Rate Set at: 8 Hz

<<active>>

Navigator

R7/Soj Navigator

Mapper

Obstacle Mapper

Asynchronous

Path Planner

Tangent Graph Planner

Locomotor

R8_Locomotor

Terrain Sensor

Stereo Engine

<<active>>

Synchronous/or
Asynchronous
e.g. Rate Set at: 10Hz
used by other activities

Stereo Camera

Stereo Processor

JPL Stereo

Pose Estimator

R8_Pose Estimator

Camera R

Camera L

Example of Navigation Architecture

Asynchronous
e.g. Rate Set at: 5 Hz

Asynchronous
e.g. Rate Set at: 8 Hz

<<active>>

Navigator
Gestalt Navigator

Path Planner
ISE Path Planner

<<active>>

Mapper
Grid Mapper

Locomotor
RS_Locomotor

Asynchronous

Terrain Sensor
Stereo Engine

Pose Estimator
R8_Pose Estimator

<<active>>

Stereo Processor
JPL Stereo

Synchronous/or
Asynchronous
e.g. Rate Set at: 10Hz
used by other activities

Stereo Camera

Camera R

Camera L

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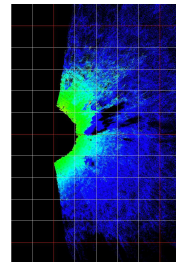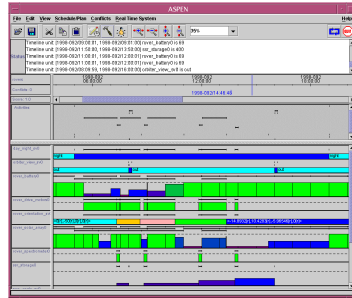
Deliverable(s)

1) Define API and infrastructure for transferring and updated obstacle maps and path information between Decision Layer and Functional Layer (3/2002)

2) Integrate technologies for merging of image wedges into a single panorama and process to extract an obstacle map to match that required by CASPER (5/2002)

3) Develop necessary infrastructure for commanding from the Decision Layer a panorama of a rover platform using mast imagery (8/2002)

4) Demonstrate a science-based scenario for visiting multiple science targets using a acquired rover panorama (10/2002)

5) Demonstrate a science-based scenario in difficult terrain with large variation in predicted path travesal due to dense rock distribution (12/2003)
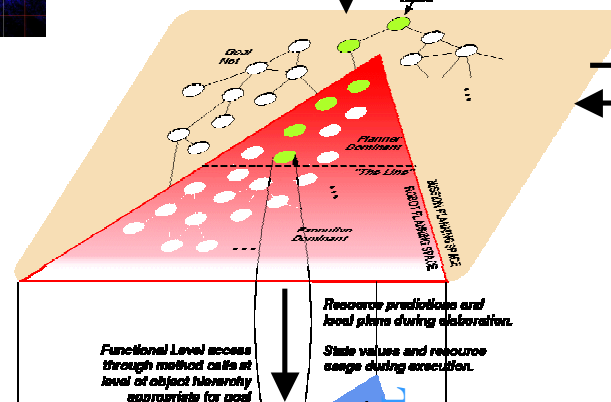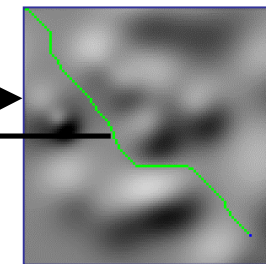
CLARAty Level I Milestone

Terrain Map from Laser
Terrain Map from Laser

D* Path Planner

DECISION LAYER

Path

Functional Level access through method calls at level of object hierarchy appropriate for goal

Resource predictions and local plans during elaboration.

State values and resource usage during execution.

Rover

Navigator

Position Estimator

Visual Odometer

Locomotor

Kalman Estimator

Rocky8

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